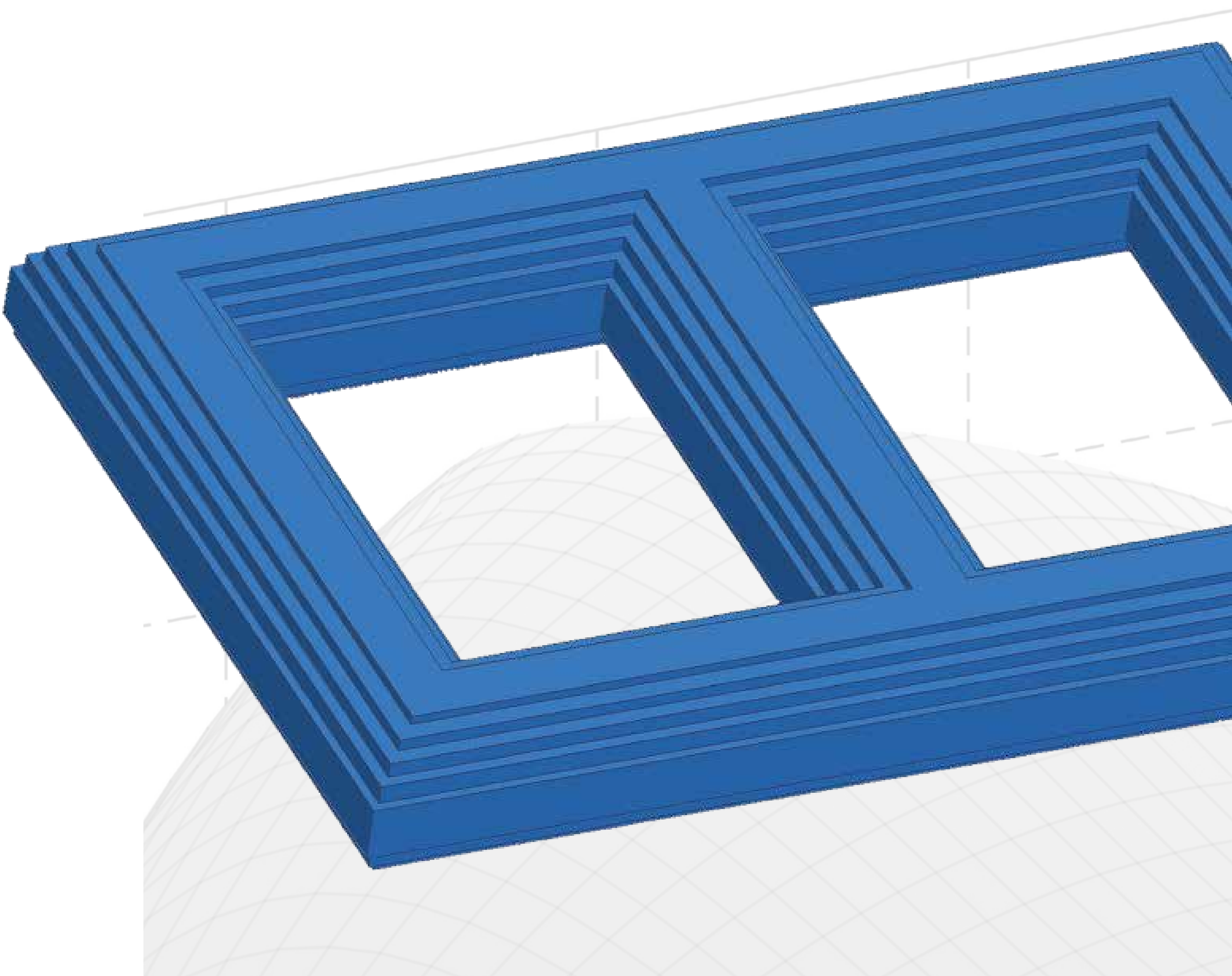


Determining transformer core losses

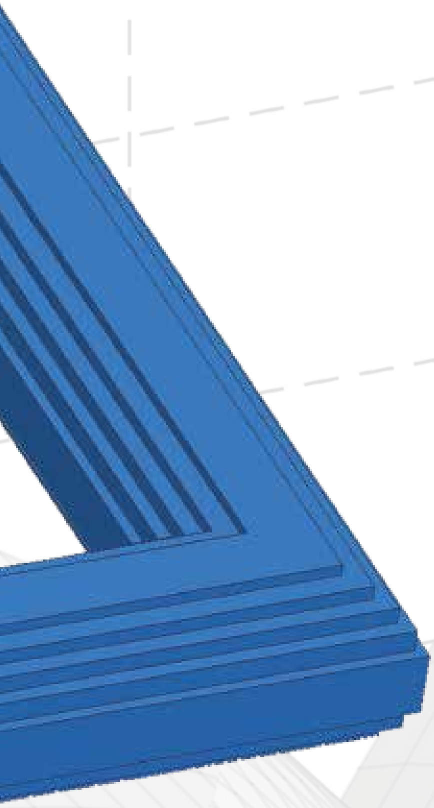
based on investigation of core material behaviour during test and operation – results

ABSTRACT

By identifying the characteristic equation of the specific no-load losses of each iron sheet based on the core configuration, it is possible to reach a high level of accuracy in detecting no-load losses over a wide range of flux density. The method is applicable and frequently used for reference as well as for new sheet types that appear on the market. The results presented in this paper are based on one year experience, showing that the total weight and volume of transformers have clearly been reduced.

KEYWORDS

transformers, core parameter, core corners, Reference Sheet Type (RST), New Sheet Type (NST), building factor



Materials with a very slight difference in no-load losses in the rest of the core (P_{Rspc}) can display a huge difference in no-load losses in the corners (P_{Espc})

Part 1 of this paper, published in Transformers Magazine Vol 2 Issue 4, described a mathematical model of a new approach for accurate determination of no-load losses. In Part 2 of the paper, the results and practical experience with the application of the new approach are presented.

4. Results

The results of this study are divided into two sections. The optimisation results define the characteristic equation of each iron sheet material, combined with its histogram density function, which shows the probability of reaching a certain tolerance. Second section concerns practical results, which provide an overview of the real deviation between the measured and calculated no-load losses using the new approach over the last year. Besides, some transformer design examples will be considered in a comparison between the first designs built many years ago and the new designs depending on the new approach. On the one hand, the core weight and consequently the whole transformer volume will be reduced. On the other, an accurate estimation of no-load losses will assist in avoiding exceeding guarantee limits and penalty consequences.

4.1 Optimisation results

Defining the core parameters means that the characteristic equation of the core material can be obtained separately for the corners and for the rest of the core (limb & yoke). Figure 6a illustrates how P_{spc} changes with the change of B for the core corners and the rest of the core. These curves result from material handling and core manufacturing for four different materials. These materials have specific no-load losses in the range of 0.75 to 0.91 W/kg and the grade range from 23 to 30, which means that the material manufacturer is not able to detect this behaviour as long as there is no information from the core manufacture. Besides, these curves could only be used concerning a certain known path of the core material, namely: certain core manufacturing plus certain material handling plus core-form transformer.

As depicted in Figure 6b, P_{Rspc} for materials 1 and 2 is similar with a very slight difference. However, there is a huge difference between the same materials in P_{Espc}.

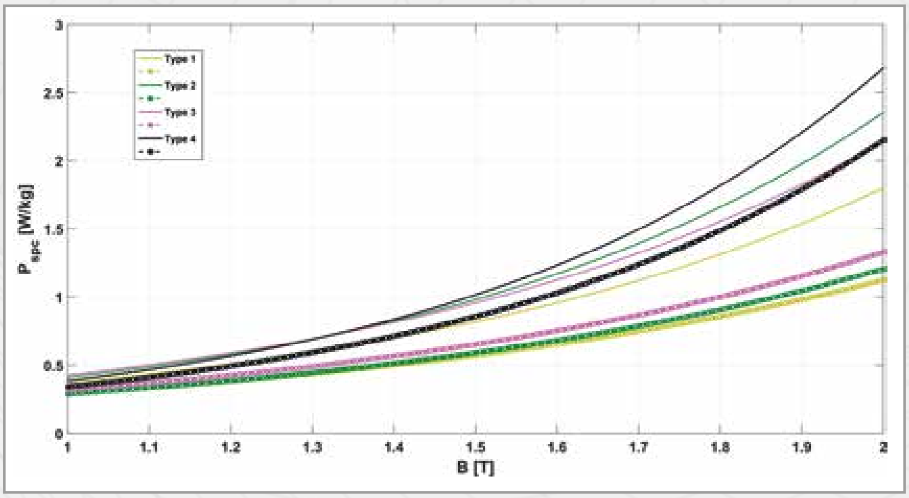


Figure 6a. Specific no-load losses for four iron sheet materials different in thickness, and specific losses for core corners and limb-yoke regions (plain lines are used for core corners, and circle markers for the rest of the core)

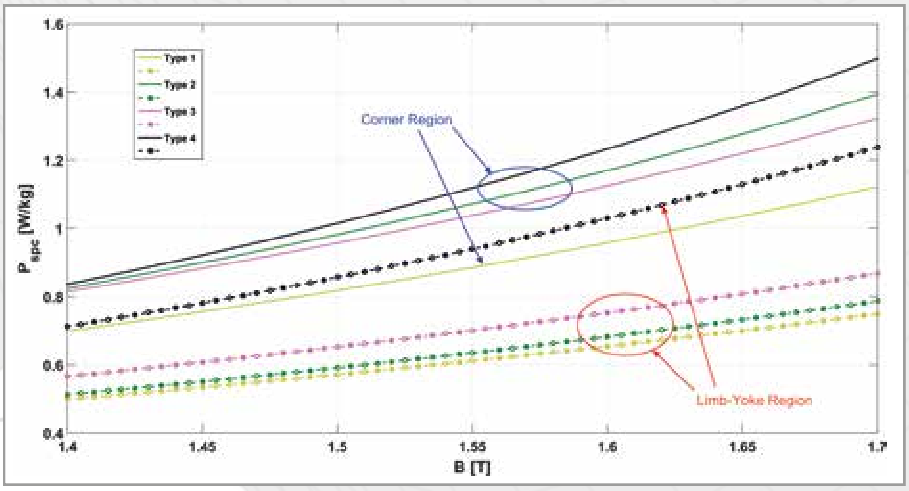


Figure 6b. Enlargement of Figure 6a for the flux density region between 1.4 and 1.7 Tesla (T)

Since the beginning of the application of the new approach for determining no-load losses in 2012, a clear improvement in the design of new and rebuilt transformers has been recorded

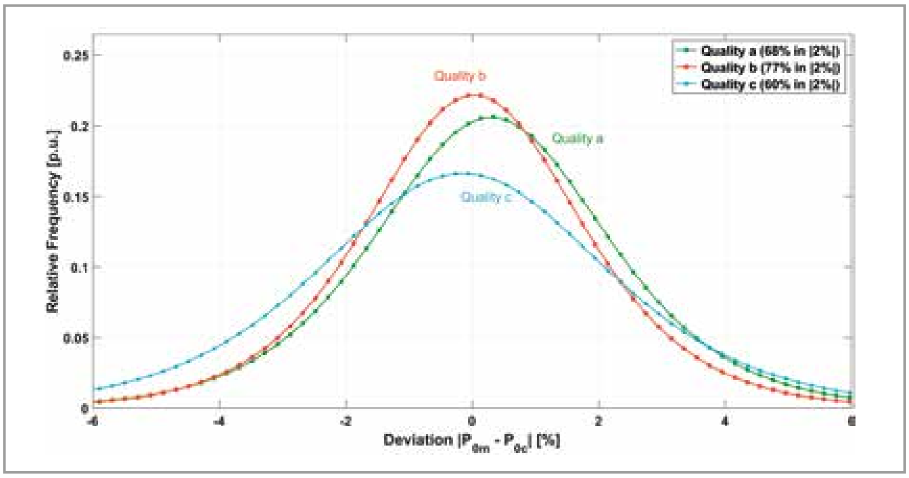


Figure 7. Relative frequency of the expected deviation for different core material qualities

Even with high accuracy for determining the core material characteristic equation, there still must be some deviation between the measured and calculated values. This deviation could be estimated using the probability density function. This function, based on a certain scattering of values, describes the frequency of the event that a certain value of this scattering occurs with respect to the total scattering. This could be presented as relative frequency or percentage frequency. In Figure 7, concerning quality a, the probability of having no deviation (equals zero) reaches 20 %. This means that if this material is used for 100 transformers, 20 of them are expected to show no deviation between the measured and calculated no-load losses. Using the probability density function, the resulting relative frequency will define a deviation interval for each core material and in turn a practical indication of the quality, as shown in Figure 7.

As there is zero deviation between the measured and calculated value, one can see that the material with quality b has the highest probability. This means that in situations where exceeding the guarantee limits will lead to refusal or high penalty, quality b is preferable. In other cases where tolerance is allowed from the customer side, the choice among qualities is taken from a cost point of view. If the tolerance is about +2 %, and from the graph one can see that the area under the three curves of a, b and c up to 2 % is nearly similar, the choice will depend on the material price and delivery time.

4.2 Practical results

Since the beginning of 2012, the new approach for determining no-load losses has been used in our own algorithm systems (built for SGB Regensburg, Germany). So far, a clear improvement in the design of new and rebuilt transformers has been recorded. The high accuracy of this approach results in cost saving in terms of the core weight, which means savings in terms of entire transformer materials and the total volume, as shown in Table 1. On the other hand, its accuracy helps to avoid exceeding the customer guarantee value. The histogram in Figure 8 covers the transformer manufacturing by SGB from the beginning of 2012, which shows a probability of 83 % in a tolerance range of ± 3 % from the calculated value.

Table 1. Amount of iron weight saving considering the new approach to improving old transformer designs according to their same requirements

Transformer data	Iron weight saving [%]
110 MVA (50 Hz) 110/30 kV	4.0
80 MVA (60 Hz) 115/69 kV	18.3
35 MVA (50 Hz) 69.2/9 kV	3.4

Figure 8 shows an average deviation of -1.7 % with the standard deviation of 1.7 %. This means that the measured no-load losses, on average, lie under the estimated value by 1.7 %, where the lowest recorded deviation from the calculated value lies at 3.4 % (1.7 % + 1.7 %). The histogram also includes the NST amount, whose P_{spc} estimation has improved with time, as more information is gained. A very important advantage of the new approach is that the quality of RST is always under monitoring. If the deviation between the measured and calculated P_0 is out of the expected range, the history path of the core material is investigated from the sheet manufacture to the transformer test.

Conclusion

The new approach is very promising in the present and the future, providing an opportunity for quality control not just for the core material types but also for the entire core manufacturing process. Of course, as for any method or approach, there are benefits and risks. One of the main advantages is implementing the building factor in the difference between P_{Espc} and P_{Rspc}, which seems to be a function of flux density as shown in Figure 6. The main risk lies in detecting the core parameter for NST. Some precautions must be taken when using NST to avoid any undesirable results or deviations. However, until today only one type of NST has shown unexpected results, which has been proved to have resulted from the change of quality of the iron sheet manufacturer. During the application of this NST, the sheet category has changed from NST to RST based on the acquired measurement history.

A very important advantage of the new approach is that the quality of RST is always under monitoring

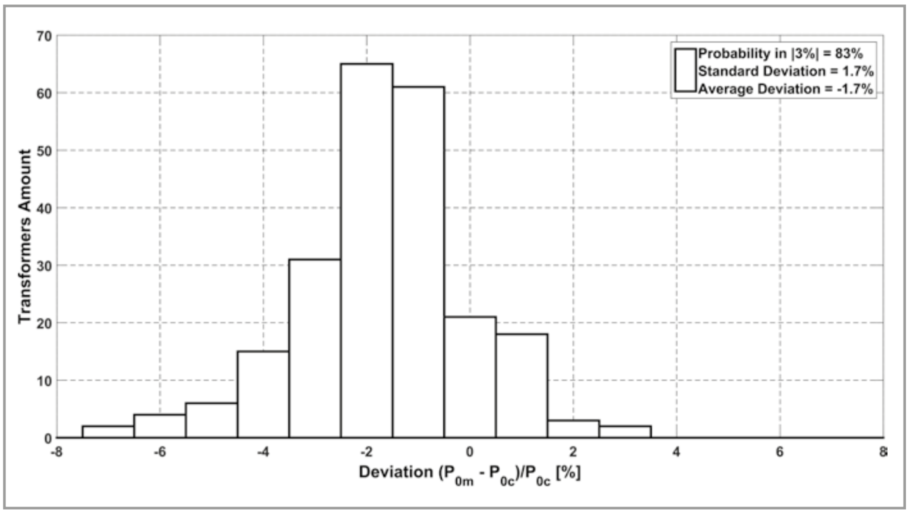


Figure 8. Histogram of the deviation of no-load losses from 2012 until today, including over 200 transformer designs (different core designs with different material types)

The main risk of the new approach may occur while detecting the core parameter for NST, and some precautions must be taken to avoid any undesirable results or deviations

Further, there are some cases of inadequate material handling by the manufacturer, so that the deviation span is wide of the estimated characteristic equation (higher standard deviation). In this case, the sheet type is used in limited amount and very cautiously to be sure that the final deviation is in the negative region, as shown in Figure 8, in the range between -4 and -6 % (less than 10 transformers in 2 years). This method has already been applied to over 1,000 units.

One of the main principles of this method is that changing of the core corners weight depends only on the changing of the core cross sectional area, which is inversely proportional to flux density if the volts per winding turn are kept constant. If changing the limb and/or the yoke lengths is causing changes in the corners volume/weight, then another consideration must be taken into account to estimate P_{spc} in an accurate way. In this case a 3D-illustration is required based on the changes in the core weight and flux density. However, as mentioned before, each transformer manufacturer will have its own characteristic equation for its own sheet types. In all cases, the principle of the new approach is the same – one characteristic equation for the corner and one for the limb-yoke regions.

Correction of the equation (1) from Part 1 of this article published in Volume 2, Issue 4 on page 23:

$P_0 = G_E \cdot P_{Espc} + (G_T - G_E) \cdot P_{Rspc}$

The new approach is a continuous process of quality improvement. A cyclic investigation has been performed over one year to increase its accuracy and avoid any undesirable deviations caused by any segment in the material chain: from iron manufacturing to transformer test. A high accuracy of this method has resulted in cost savings in terms of the core size and consequently, the entire transformer material needs.

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